DESIGN AND IMPLEMENTATION OF MULTILEVEL INVERTER WITH REDUCED HARMONIC LEVELS FOR SOLAR PV SYSTEM

A SYNOPSIS

Submitted by

GEEVARGHESE MATHEW KURIAN

(Reg. No. 201609239)

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KALASALINGAM ACADEMY OF RESEARCH AND EDUCATION

(DEEMED TO BE UNIVERSITY)

ANAND NAGAR, KRISHNANKOIL – 626 126

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1. Introduction

Currently, the photovoltaic (PV) approaches represent a critical improvement in utilization of a clean energy source. Since the energy consumption is increasing day by day, out of proportion with regard to fossil fuel resources, the use of renewable clean energy source is gaining importance globally. With multiple efforts, grid-connected PV systems are the most preferred advancements to extract energy in developed countries. The power converter forms an essential part for the functioning of solar photovoltaic system. The power converter adjusts the voltage source towards the inverter's operating voltage and functions as a maximum power point (MPP) tracker [1]. The use of fuzzy controllers has proved successful in various fields, including power converters to control the pulse width of the inverters, and lighting in photovoltaic powered systems [2]. A new solar PV cell power supplying system is being developed to improve system performance and ease the monitoring of control circuit. To monitor the maximum power point of the solar PV arrays, the novel system uses a boosting type bilateral converters as a charging/discharging and a primary controller circuitry through a single monitor solar cell [3].

Boost converter efficiency assessment has been conducted earlier, we will discuss it in the setting of relatively low voltage and low power. This will result in simple yet effective algorithms for selecting metal-oxide-semiconductor field-effect transistor (MOSFET) and additional elements [4], [5]. A resonant boost dc-dc converter is used in a photovoltaic generating system's supplementary resonant circuit. It is more efficient than a standard boosting converter [6]. The PV dc-link inverter is conducted productively by pulse width modulation (PWM), but the consequences acquired in various partial shading stages have revealed that the engaged photovoltaic inputs are not functioning at their maximum power points. Multilevel Inverter are getting more attention from researchers due to the low electromagnetic interference, higher efficiency and reduced harmonics when compared to two level inverters. Harmonics can be reduced to considerably by increasing the levels in multilevel inverters [7].

2. Literature Review

In the study conducted by Wu et al. a fuzzy logic controlled single stage power converter is used for photovoltaic powered lighting applications [8]. To improve the enactment of the photovoltaic systems, the maximum power point of the solar array is monitored. The tracking algorithm modifies the converter's duty ratio in particular solar insolation such that the potential of the photovoltaic panel matches the potential of the maximum power point Veerachary et al.

[9]. Maximum Power Point Tracking (MPPT) is usually employed along with DC-DC converter to optimize the large array of pv modules. Harvesting of maximum power generated by arrays forms the main objective of MPPT by Ishaque et al. [10].

In 1980, the multilevel neutral-point-clamping inverters were presented, which are particularly modified for high-power traction applications since the spoiling voltages are the semi of the input voltage, and their output side distortions are significantly decreased [3-level pulse width modulation (PWM) terminal voltage waveform]. Lately, these converter types, principally its control techniques Iturriz and Ladoux [11] have been a vital topic in different congresses. .For maximum utilisation of the solar energy in spite of its stochastic fluctuation, the solar pv panels maximum power has to be extracted and this has to be fed to grids at unity power factor. This is done to good extent by the cascaded multilevel inverter Yushan et al. [12].

Multilevel carrier-depend PWM and multilevel space-vector pulse width modulations are the two most widely studied PWM methods in the literature; both are additions of classic 2-level PWM systems toward many stages. Researchers suggested carrier-based multilevel sine-triangle PWM inverter patterns to regulate a multilayer diode-clamping inverters utilized as a motor drive or static var compensators Tolbert and Habetier [13]. Multilayer inverters can readily supply the considerable power that a large electric drive requires. The created resultant waveforms includes extra phases as the number of stages grows, resulting in a staircase waveform approaching the ideal waveform. In addition, as the number of stories in the wave increases, the harmonics of the output waveform reduces, eventually nearing zero Tolbert and Peng [14].Cascade multilevel inverter is more commonly used due to its advantages like achieving the distributed MPPT and high grid voltage without a transformer Sun et al. [15].

3. Objective of the research

The main objective is to design novel structure of Multi-level Inverter for with reduced harmonic levels. The performance of various controllers like PI and Fuzzy Logic for Multilevel Inverter with reduced harmonic levels is to be analysed. The research is designed and divided into two sections in order to address the problems associated with standard inverters architecture. Over the first phase, an innovative single-phase 31-level inverter with a minimum number of switches is planned for solar panel system. The proposed inverter incorporates a fuzzy logic-based MPP and boosting converter that excerpt the most power from the solar PV module. Furthermore, it produces 31 stepwise output voltages with low Total Harmonic

Components. The Total harmonic distortion (THD) obtained is within IEEE 519 standard norms.

For a single-phase Solar PV system, a maximum power point-integrated Fuzzy Logic Controller was coupled with a 15-level Multilevel Inverter topology during the second phase. MPPT would gather the maximum electricity from the photovoltaic system under varied degrees of solar irradiation throughout the day. The Fuzzy controller evaluates the best duty ratio to evaluate the maximum outputs of the DC-DC boosting converter utilising power output from the Photovoltaic cells with temperature and solar irradiance as input. Fuzzy controller could deal with ambiguous input, doesn't require exact mathematical formulas, and could interpret nonlinear functions successfully. Additionally, Fuzzy logic controller is more successful than other control systems. Harmonic Distortion is reduced and kept within the prescribed range, according to IEEE standard 519. The suggested model is both financially sustainable and straightforward for implementation.

MATLAB/Simulink is utilised to model the anticipated architecture. The suggested inverter incorporates a fuzzy logic-driven MPPT and boosting converter to excerpt the most power from the solar PV cells. Furthermore, it produces 31 stepwise output terminal voltage levels with low Total Harmonic Components. The THD obtained is within IEEE norms. While in the 15 stage multilevel inverters, the performances of voltages total harmonic distortion in FLC-MPPT is 0.91 percent, which is lesser than P&O-harmonics MPPT's in the system of 3.51 percent. As a result, this research would be a valuable contribution to the field of power electronics using Fuzzy controllers for power grids.

4. Design of solar PV integrated with boost topology

As the Globe worry about greenhouse gases grows and traditional non-renewable supplies dwindle, renewable energies (sun, wind, and geothermal, for example) were gaining attraction as alternative energies. PV panel's energy has been commonly used in various power generating devices owing to its benefits of electricity generation form, easy handling, zero noise, and so on. Because of the heavy price of Photovoltaic array construction, MPPT controls has become a crucial problem for Photovoltaic system.

There are two major problems that impede the construction of accurate and fast set of rules for the boosting converter's voltage source. The first is that the Photovoltaic generator's MPP changes unpredictably with sun's electricity and temperatures. As a result, the boost converter must be regulated in a changing operating condition.

A Photovoltaic cell's circuitry schematic includes a diode and a current source which are connected in parallel. It generates the current I_{Ph}, which is directly proportional towards the irradiation F_s [W/m^2], the ambient temperature T_a [^{o}C], the output current I_s [A], and the voltage drop V_s [V]. Kirchhoff's current law could be used to represent the distinct equations. Figure 1 depicts the Photo Voltaic circuit layout.

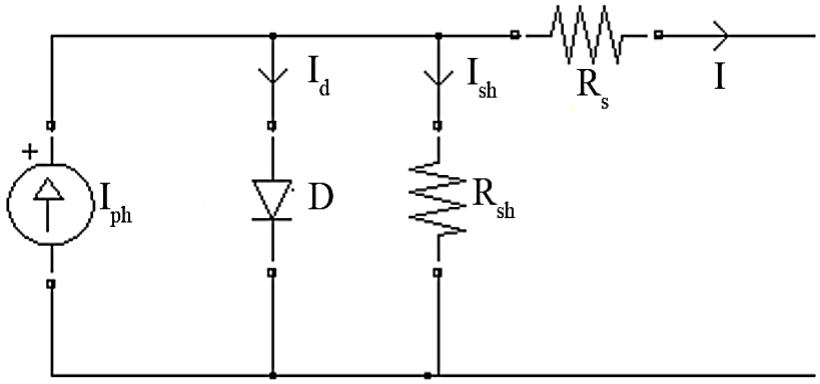

Figure 1. Photovoltaic circuit layout

From the circuit the load current of solar cell is derived as follows

$$I = I_{ph} - I_d - I_{Rsh} \quad (1)$$

$$I = I_{ph} - I_0 \left(e^{q\frac{(V+IRs)}{\propto kT}} - 1\right) - \left(\frac{V+IRs}{Rsh}\right) \quad (2)$$

The DC-DC converter transforms greater and lesser voltages from Photovoltaic modules towards a controlled DC terminal voltage. A higher-efficiency DC-DC converter is designed for this operation. These devices can temporarily store electrical energy for converting direct current from one voltage level to another level. The Photovoltaic module's voltage can be controlled by a DC-DC converters circuitry. A dc/dc converter serves as the link between both the demand and the photovoltaic array. It functions as a switch between demand and solar cells. The load resistances may be modified to provide high power by simply varying the duty ratio. Figure 2 illustrates the overall depiction of the Power converter.

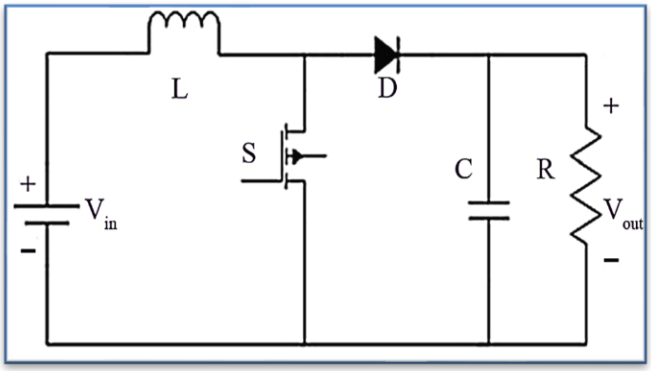

Figure 2. DC-DC converter equivalent circuit diagram

The output terminal voltage of the DC-DC power converter is

$$\frac{V_0}{V_i} = \frac{1}{1-d_c} \tag{3}$$

The value of duty ratio, inductors, and capacitors have been determined using the ensuing formulas,

$$d_c = 1 - \frac{V_i}{V_0} \tag{4}$$

$$L_m = (1 - d_c)^2 \text{ x } d_c x \frac{R_1}{2f_s} \tag{5}$$

$$C_m = V_0 x \frac{d_c}{R_1} x f_s x \Delta V_{re} \tag{6}$$

Fuzzy system seems to have an adaptability and may produce resilient response of the system in the presence of disturbances, parameters change, and load disruption. It has been widely utilized to regulate systems that are inadequate, irregular, or inaccurate. Fuzzy logic control has been effectively functional in the production of power electronic devices that govern and manage dc-dc converters, PWM reference inverters and MPPT in energy conversion systems. Fuzzy system really doesn't need predictive results among those processes [8].

The operating points of photovoltaic modules should be modified in line with working conditions so as to change the current and voltage of photovoltaic modules in order to collect the greatest power. MPPT may be used to collect the greatest power from a solar Photovoltaic system's outputs. The Controllers has been used to specify the duty cycle of the Power converter in the MPP configuration. The FLC's inputs has been assigned towards the erroneous values and changes in error. Fuzzy output, system inferences, number of rules, and defuzzification are the Fuzzy logic controller building pieces. The scheme of the FLC is seen in Figure 3.

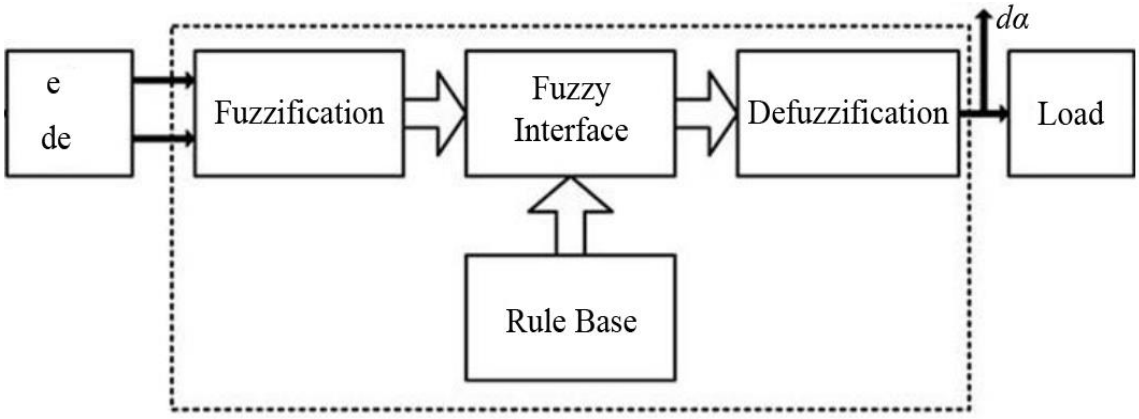

Figure 3. Configuration of the FLC

The current and voltage are responsible for the values of error and deviations in error of the PV system. The values have been estimated using equations (7) and (8).

$$e(k) = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \tag{7}$$

$$\Delta e(k) = e(k) - e(k-1) \tag{8}$$

Where

e(k)	error value at sampling period (k)
e(k-1)	error value at sampling period (k-1)
Δe(k)	changes in error
P	power
V	voltage

The implication system and membership functions employed in the fuzzy set have been prepared using trial and error method. Fuzzification values of error and changes in error have been illustrated in figures 4 and 5. The values of changes in duty cycle (Defuzzification) has been displayed in Figure 6. The fuzzy surface view has been illustrated in Figure 7. The rule base employed has been provided in Table 1.

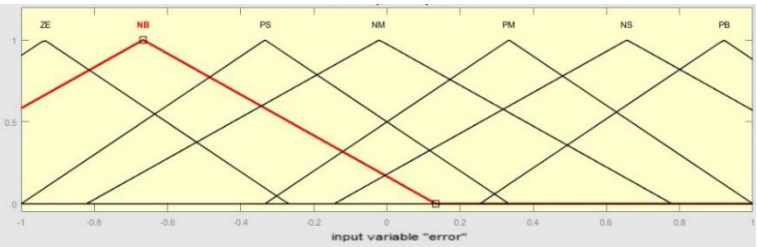

Figure 4. Membership function for e(k)

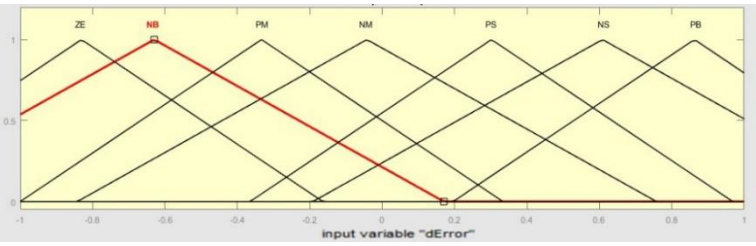

Figure 5. Membership function for e(k-1)

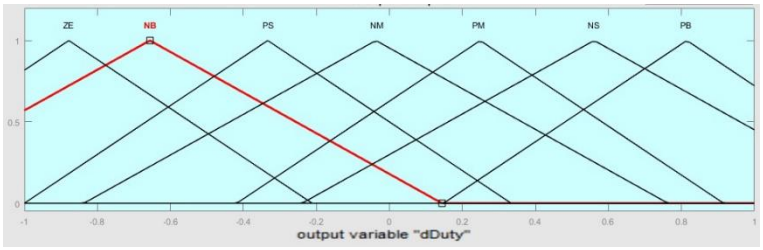

Figure 6. Membership function for d_c

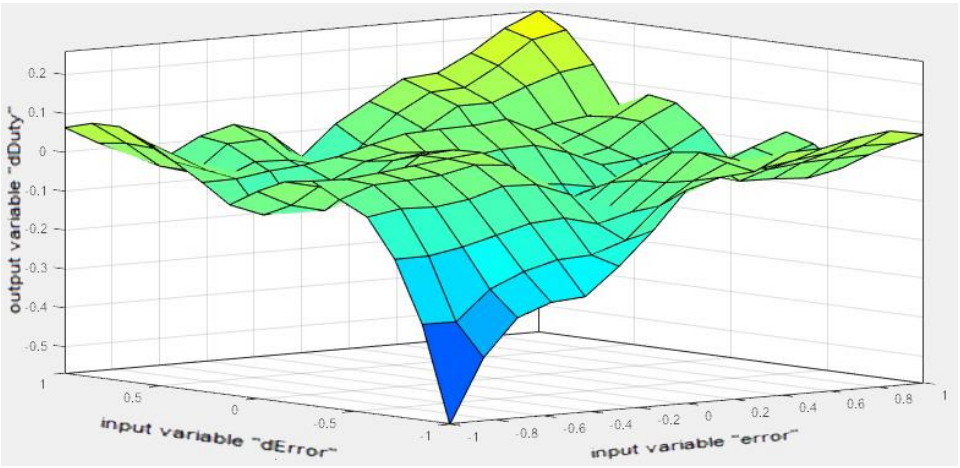

Figure 7. Fuzzy surface view

Table 1. Rules table of FLC

e / de	ZE	NB	PS	NM	PM	NS	PB
ZE	NB	NB	NB	NB	NM	NS	ZE
NB	NB	NB	NB	NM	NS	ZE	PS
PS	NB	NB	NM	NS	ZE	PS	PM
NM	NB	NM	NS	ZE	PS	PM	PB
PM	NM	NS	ZE	PS	PM	PB	PB
NS	NS	ZE	PS	PM	PB	PS	PB
PB	ZE	PS	PM	PB	PB	PB	PB

5. Results of multilevel inverter topology

The multilevel topology's objective is to minimize the voltage level of the switches. As a result, it is typically employed in high-power applications. It features reduced dv/dt, minimal line current distortions and decreased frequency deviation through combining voltage output in multilayer configuration. Various layouts has arisen in latest years of the benefits of multilevel architecture

5.1 Results of Phase I: 31 level CHB-MLI topology

Figure 8 depicts the proposed 31-level Multilevel inverters, which includes 14 uni - directional switching devices S_1 to S_{14} and four DC voltage supplies V_1, V_2, V_3, and V_4. Because the voltage level of four DC sources is set with different ideals, it is asymmetrical. The DC voltage supplies in this investigation are set at a 1:2:4:8 ratio, and the source voltages are $V_{dc} = V_1 = 15$ V, $V_2 = 30$ V, $V_3 = 60$ V, and $V_4 = 120$ V, respectively.

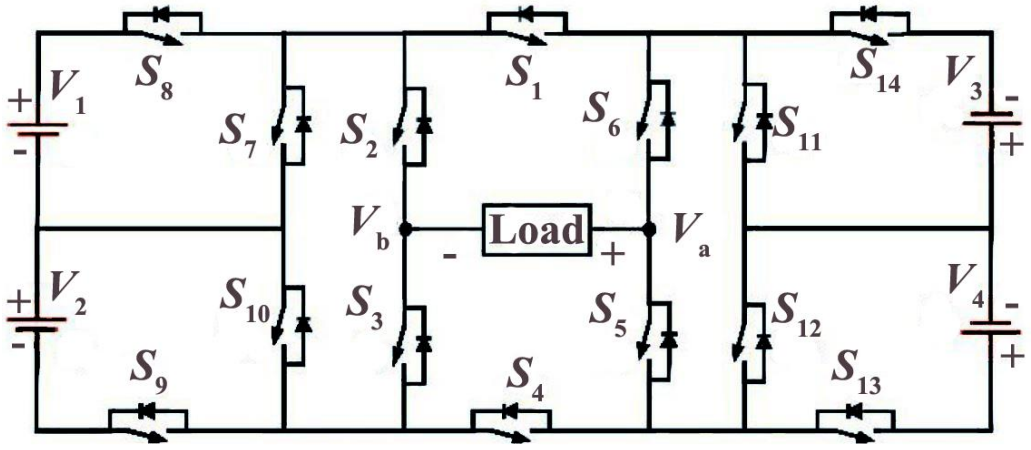

Figure 8. Suggested 31-level MLI's architecture

The Fuzzy logic control indents to track the MPP fast in the variable irradiation and climatic variations, but the P&O gains the MPP ineffectively. They suffer with further fluctuation in MPP and power outage would be significant. The suggested FLC-based Maximum power point method for photovoltaic panels has a higher output voltage than the Perturb and observe Maximum power point method. Figure 9 show the Multi - level inverter voltage output and Figure 10 shows harmonic distortion voltage.

The voltage profile of the Total Harmonic Distortion (THD) is 3.18 percent at 230 V, which is the lowest. It means that the findings are well within the bounds of IEEE standard 519. Figure 11 depicts a hardware configuration for obtaining testing findings in order to certify the implementation of the anticipated layout. The power strip in this experimental model is an

IGBT - IRG4BC20SD. The Xilinx Spartan 3E-500 FPGA controller was utilized to produce gate pulses for switching devices.

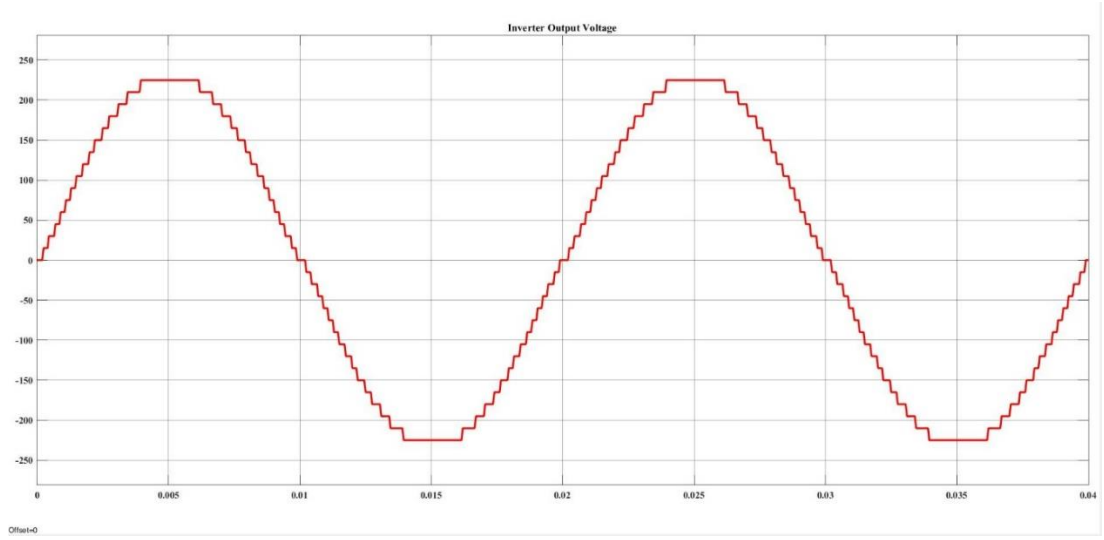

Figure 9. Output voltage of MLI

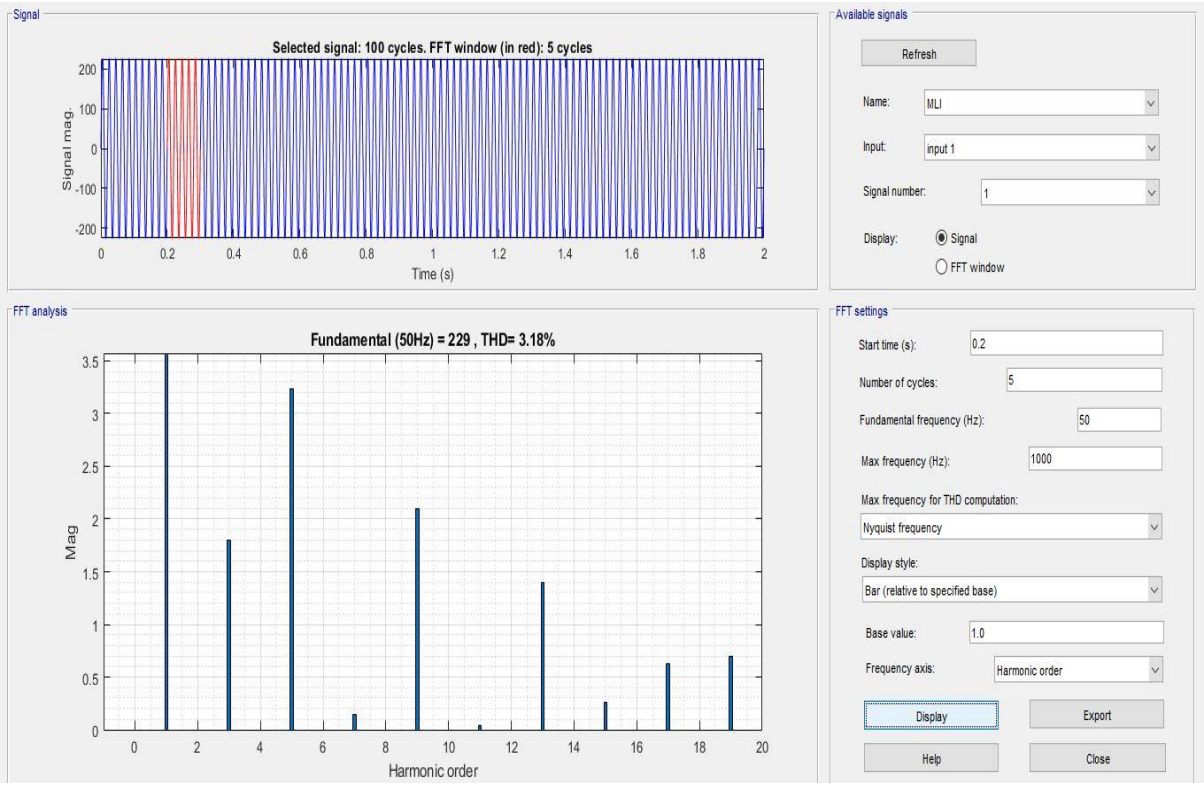

Figure 10. The output voltage Harmonic distortion

The equipment configuration includes a variable resistor of 100 ohm and an inductance load of 100mH and a carrier frequency of 2 kHz were used. The output data was recorded using a Tektronix TPS 2024 Digital Storage Oscilloscope (DSO). Because of their ability to provide better energy conversions with a less system expense, basic switching frequency processes are preferable to high switching frequency techniques.

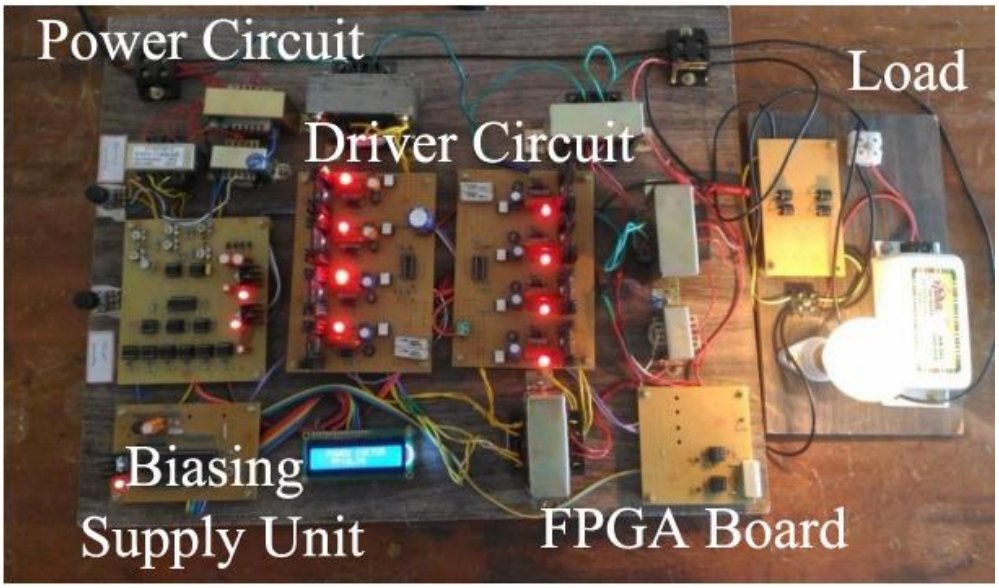

Figure 11. The suggested work's experimental setup

5.2. Results of Phase II: Fifteen-level MLI

During the phase II, multilevel inverter includes switches as well as three voltage inputs. Multilevel inverter is well-suited for complex systems owing to its ability to generate voltage with reduced harmonics and obtain higher voltages with reduced-power components. MLI can meet increasing loads and power quality requirements while minimizing Harmonic distortion. MLI provides advantages such as increased Photovoltaic cell performance, mixing capability of various inputs and system idleness. MLI voltage control has been performed using separate DC lines. As a result, the MLI serves as a cost-effective, competent, robust and persistent application in an SPV system. In Figure 12, an RL circuit is connected to MLI and the output voltage of MLI are shown.

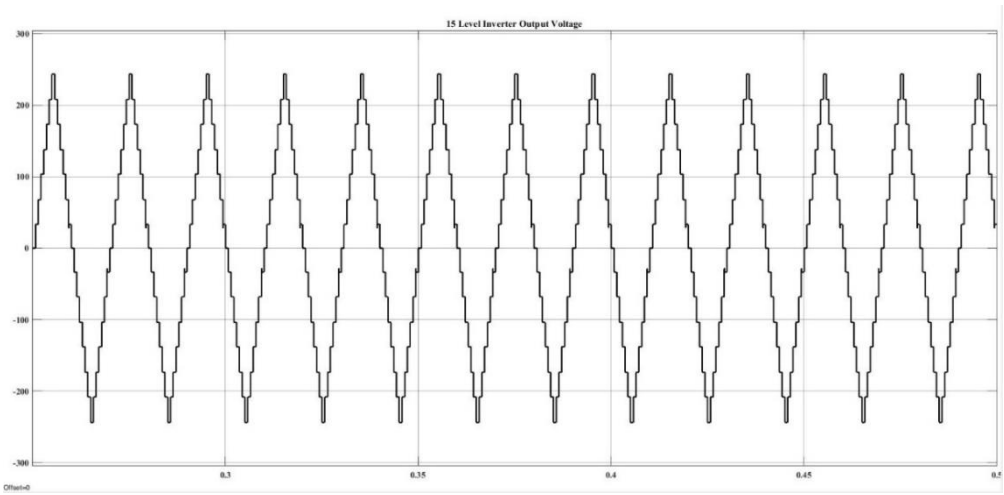

Figure 12. Output current and voltage patterns

The distortions produced in the proposed study are 0.91 percent at 230 V. Figure 13 depicts the harmonics spectra of the suggested technique. It means that the findings are within the bounds of IEEE standard 519 [16].

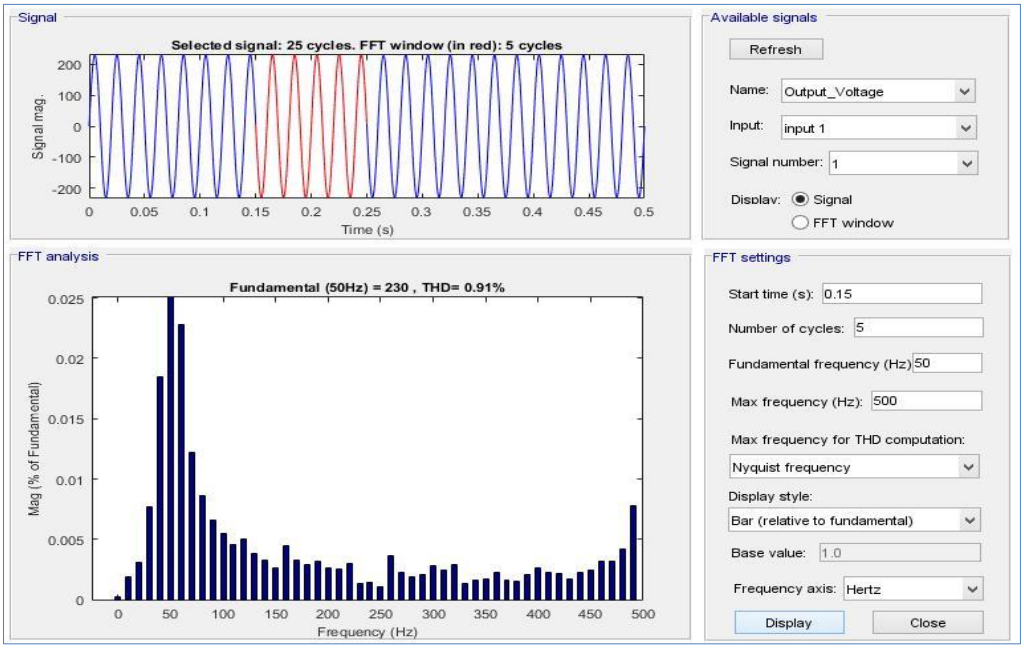

Figure 13. FFT investigation of the suggested work

Furthermore, have shown that the voltage output of a 15-stage Multi - level inverter Power converter is greater as well as the harmonic distortion is less than the Perturb and observe approach [17]. Despite recent variations in temperature and irradiation, the Perturb and observe techniques provide very efficient and effective maximum power point capabilities. Rigorous testing reveals that the proposed approach may surpass the general framework. As associated to the normal FLC-based MPP technique, the optimal asymmetric FLC-based MPP approach might improve transitory duration and MPPT precision by approximately 25.8 and 0.98 percent, respectively, under STC. An evaluation of multilevel inverters adoption is achieved by the P&O and FLC MPPT methodologies. Photovoltaic system technologies convert sunlight into electricity. When photons contact photovoltaic panels, particles all throughout substratum are becoming more involved; these particles are then driven off most of the modules to create direct current (DC). Most often, an inverter will be utilized to convert the dc to ac, making it much more instantly usable via consumers, because most energy gadgets only operate on alternating current (AC).

To verify the implementation of the proposed topologies, a hardware setup for collecting experimental findings has just been constructed, as shown in Figure 14.

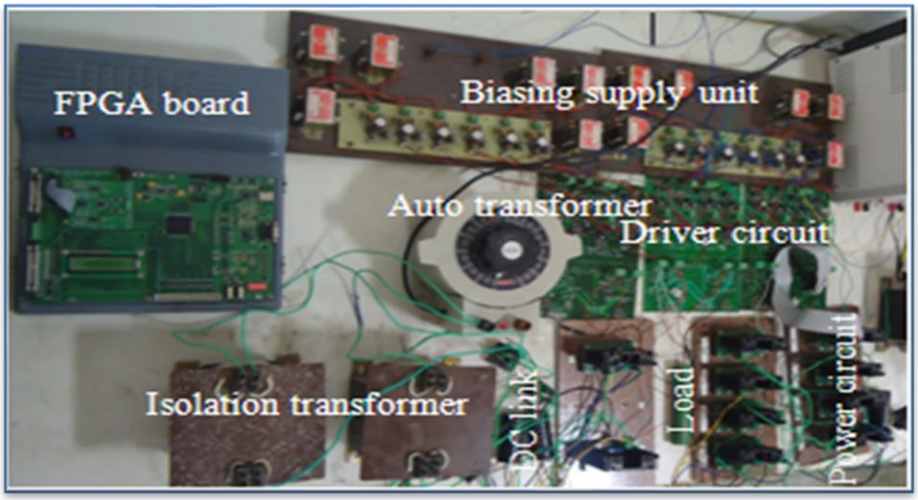

Figure 14. Hardware setup of the suggested work

The power switch in this test system is an IGBT - IRG4BC20SD. To create gating signals for switching devices, the Xilinx Spartan 3E-500 FPGA controllers was employed. Spartan-3E FPGAs were applicable to a wide range of consumer's electrical uses, including internet connectivity, network services, monitors and digital television technologies, due to their extremely low cost. The hardware design included a resistor of 100ohm, an inductance of 100mH and with frequency band of 2 kHz. The output findings were recorded using only a Tektronix TPS 2024 Digital Storage Oscilloscope (DSO), instead of utilizing conventional methods, continually collects and evaluates the received signals. Because of the evident extra trigger, storage, prediction and measuring features that it generally provides, it is now the most often used type of oscilloscope. Essential switching frequency technologies are preferable to those needing higher switching patterns due to their capacity to transform greater electricity at a lower cost.

6. Conclusion

Throughout Phase I, in this project, an asymmetric 31-level multilevel inverter architecture was developed and implemented. The proposed multilevel inverter has a small number of semiconducting components that reduces both the pricing and the size of the inverters. Consequently, the MLI's effectiveness and reliability improve. The estimated multilevel inverter requires the fewest number of components to provide the desired output terminal voltage level with the lowest amount of Harmonic distortion. The proposed approach is easier on the 31 level inverter than the existing multilevel inverters. Additionally, a quantitative examination of the suggested multilevel inverters in asymmetrical modes shows that the projected multilevel inverter requires a low switch counts to achieve the desired values.

The suggested CHB MLI unique features like reduce harmonics, increase efficiency and flexibility properties. Although they are not often used in sectors now, they offer enormous future opportunities.

This study presents the modelling of a 1-phase 15-level SPV-based multilevel inverters using the FLC-based Maximum power point throughout phase II. The MCPWM method was used to generate the 15-level voltage output. The filtering circuit improves the output voltage waveform of the multilevel inverters. On a solar system, the FLC-based Maximum power point method provides better output voltage than the P&O-based MPPT algorithm. The proposed effort is about using evolutionary computation approaches to develop a distributed energy system for effective grid connected and greener energy generation. As a result, the suggested research is capable of increasing output voltage, decreasing voltage output response time, reducing power loss in switches, and lowering Harmonic distortion during varying environmental circumstances. The suggested study, according to the authors, presents an important alternative for regulating multilevel inverters on a solar SPV system. In the future, the researcher hopes to expand this study to include development of grid connected single phase or three phase system. Conversely, switching designs based on the unified method, such as uni - polar automatic PWM, simulated stages PWM, and multilayer central switching, can be used to create switching pulses.

7. Organization of the Thesis

The works carried out in the thesis have been organized into five chapters.

Chapter 1 briefs the introduction regarding solar PV based boost converter for multilevel inverter. And also explores the previous works and literature, problem formation through literature review and objectives of the research additionally elaborating the overview of the research work.

Chapter 2 defines the solar based boost converter for obtaining optimal voltage gain values. Also the Modeling of the solar PV as well as boost converter has been provided.

Chapter 3 provides the detailed descriptions and implementation of Maximum power point tracking based fuzzy logic controller.

Chapter 4 details the multilevel inverter along with its technical commercial importance. Then, the chapter shows the results of the 31level and 15 level MLIs in two different phases along with their hardware results.

Chapter 5 sums up the overall work done and glimpse the potential directions for future research.

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List of Publications

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